What have we learned from CGILS?

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Outline

1. Background
2. Constant forcing versus transient forcing
3. Cloud feedback results
4. Physical mechanisms
5. Summary

Purpose:

To understand the mechanisms of cloud feedbacks, and thus sensitivities of climate models.

Goals:

1. **To understand cloud feedbacks in SCMs**
2. **To evaluate SCM cloud feedbacks using LES**
3. **To interpret GCM cloud feedbacks by using SCM results**

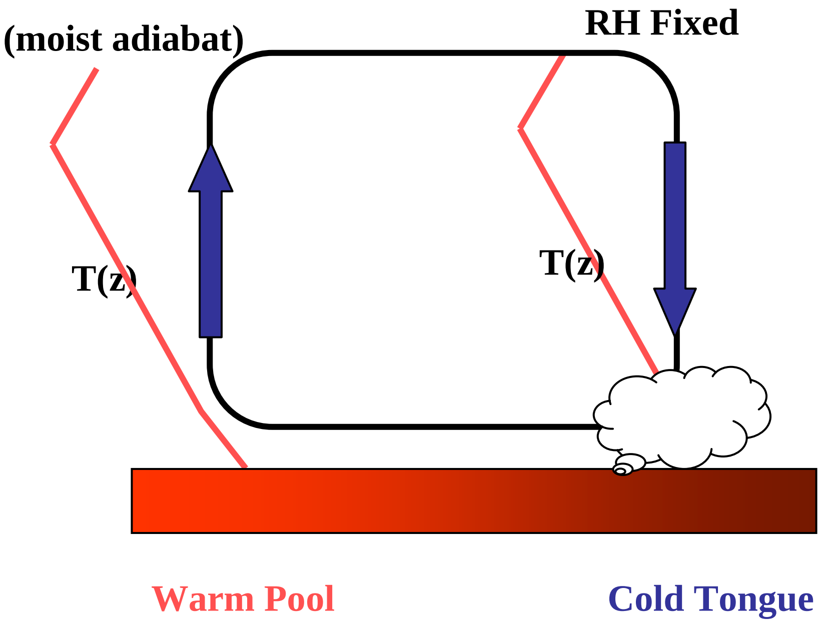
SCM (16)

CAM4 (Hannay, Zhang)
CAM5 (Hannay, Zhang)
CCC (Austin)
CSIRO (Franklin)
ECHAM-ETH (Siegenthaler-LeDrian, Isotta)
ECHAM-MPI (Kumar, Stevens)
ECMWF (Koehler)
GFDL (Golaz, Zhao)
GISS (Wolfe, Del Genio)
GSFC (Molod, Bacmeister, Suarez)
JMA (Kawai)
LMD (Brient, Bony, Jean-Louis)
RACMO (Neggers)
SNU (Park, Kang)
UKMO (Webb, Lock)
UWM (Larson, Senkbeil)

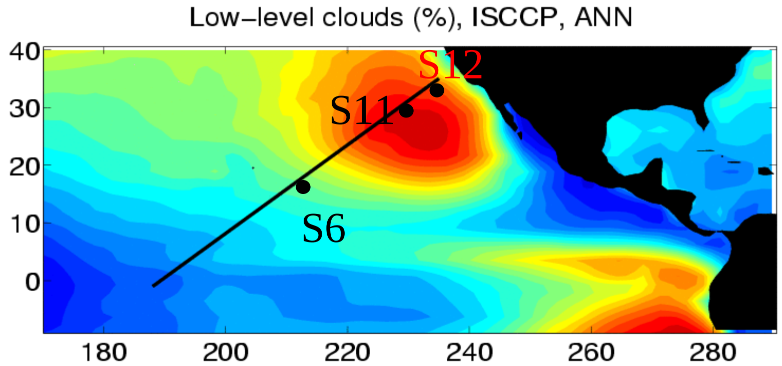
LES (5)

DALES (de Roode, Siebesma)
SAM (Blossey, Bretherton, Khairdinov)
UCLA (Sandu, Stevens, Heus)
UCLA/LaRC (Cheng, Xu)
UKMO (Lock)

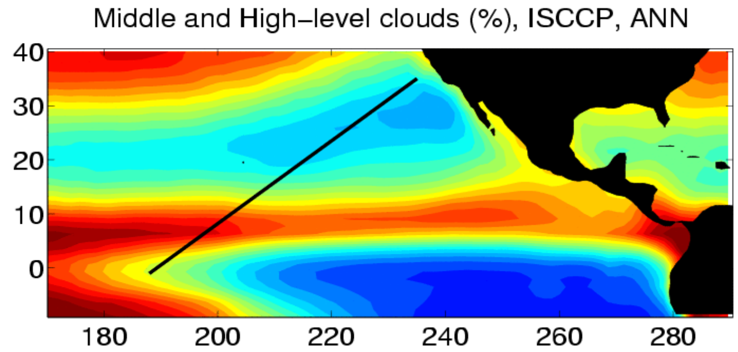
GPCI



(moist adiabat)
RH Fixed
T(z)
T(z)
Warm Pool
Cold Tongue



Low–level clouds (%), ISCCP, ANN
S12
S11
S6
40
30
20
10
0
180
200
220
240
260
280



Middle and High–level clouds (%), ISCCP, ANN
40
30
20
10
0
180
200
220
240
260
280

Rounds of iterations among participants

SCM

Round 1:

Large-scale forcing modified from Zhang and Bretherton (2008).

Round 2:

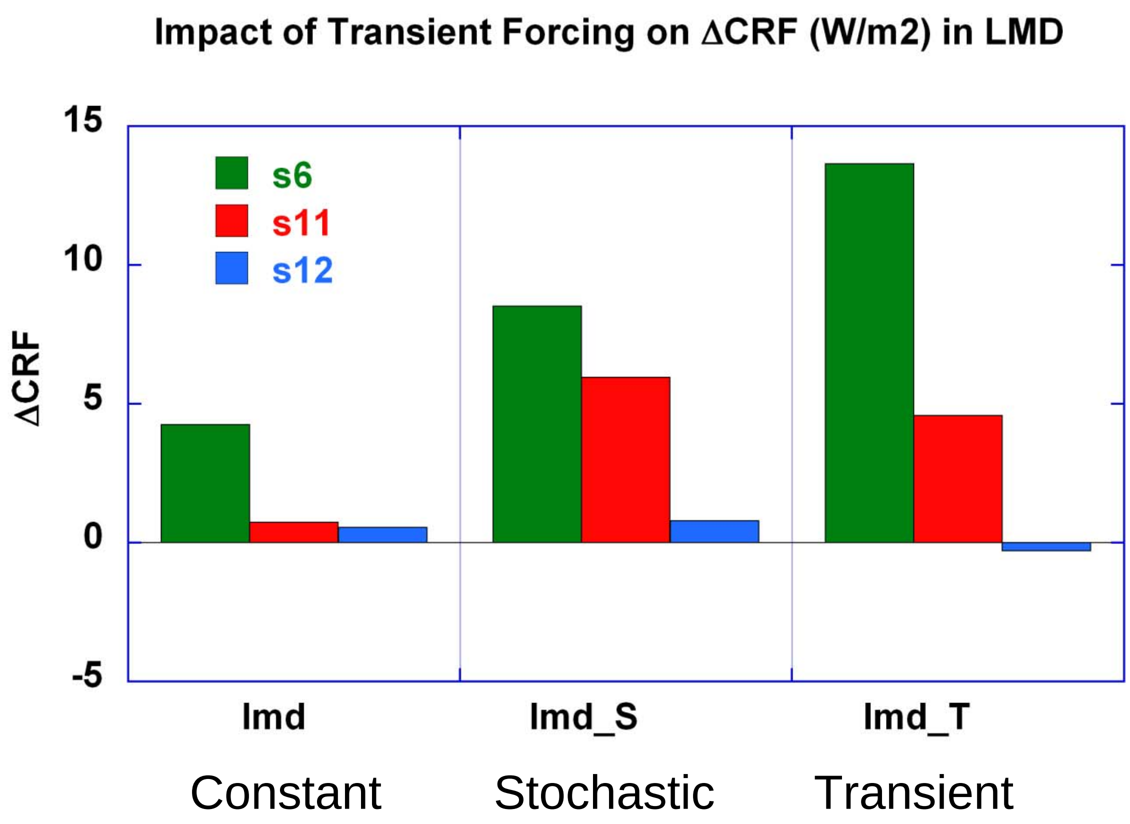
Large-scale forcing and initial condition modified in the boundary layer to be the same as for LES

Round 3:

Transient forcing added.

LES

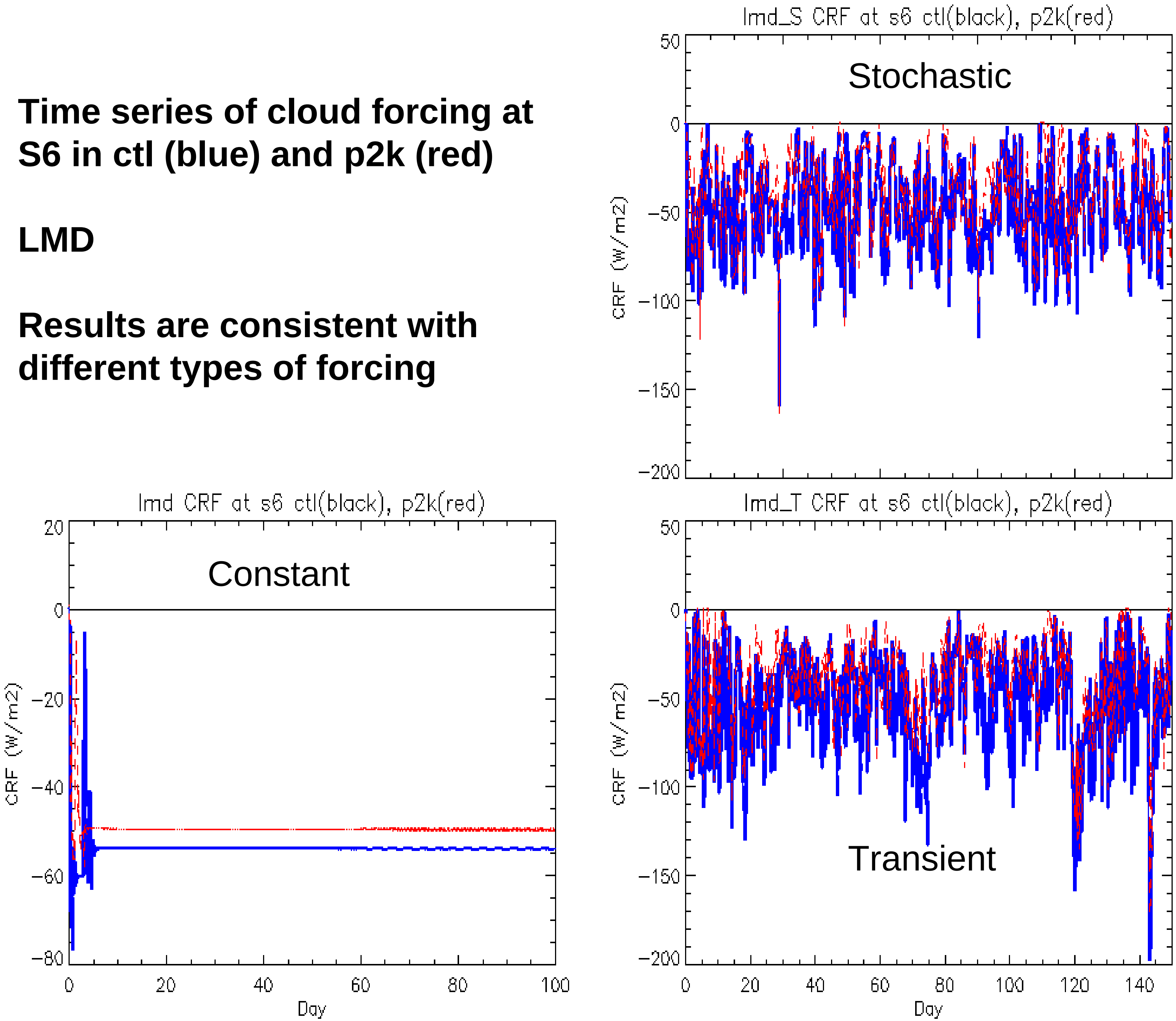
Rounds: Peter's talk


Impact of Transient Forcing on ΔCRF (W/m2) in LMD
15
10
5
0
-5
ΔCRF
s6
s11
s12
lmd
lmd_S
lmd_T
Constant
Stochastic
Transient

Time series of cloud forcing at S6 in ctl (blue) and p2k (red)

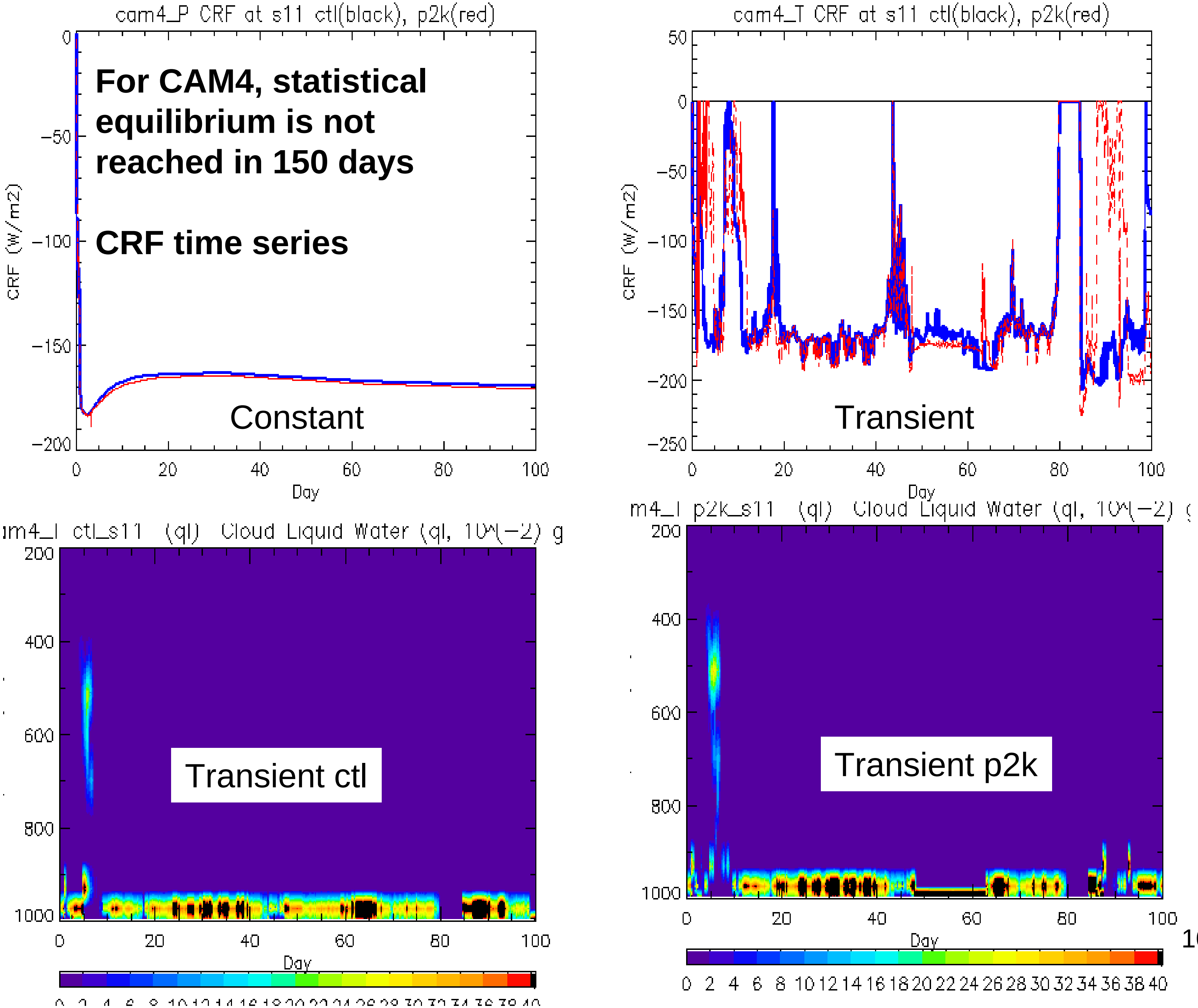
LMD

Results are consistent with different types of forcing



- **Cloud feedback signal shows up consistently under constant forcing, stochastic forcing, and transient forcing in the LMD model**

- **But transient forcing poses problems for some models, since quasi-equilibrium states are not easily reached.**



cam4_P CRF at s11 ctl(black), p2k(red)
For CAM4, statistical equilibrium is not reached in 150 days
CRF time series
CRF (W/m2)
Constant
Day
cam4_T CRF at s11 ctl(black), p2k(red)
Transient
ctl_s11 (ql) Cloud Liquid Water (ql, 10^(-2) g
Transient ctl
p2k_s11 (ql) Cloud Liquid Water (ql, 10^(-2)
Transient p2k
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40

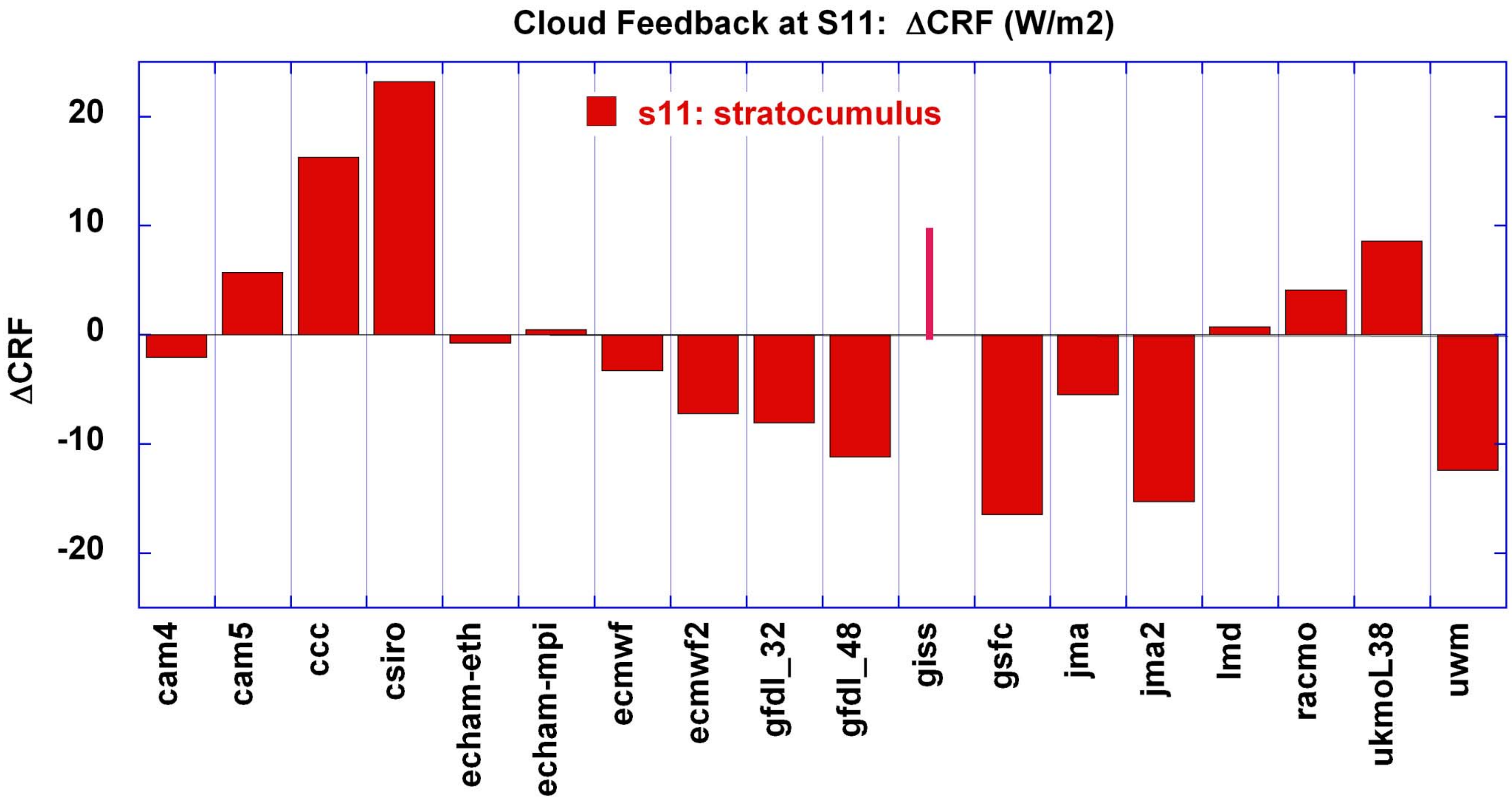
- **Use of transient forcing is left to participants.**

- **Transient forcing is recommended if**

  (1) statistical quasi-equilibrium simulations are not reached, or

  (2) SCM results are suspected to be different from processes in GCMs

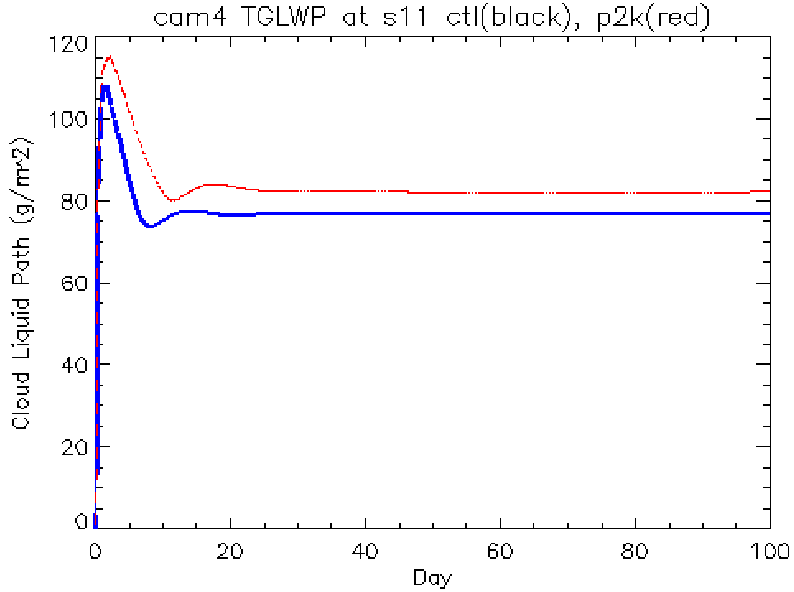
- **In the intercomparison, results from constant forcing will be shown.**

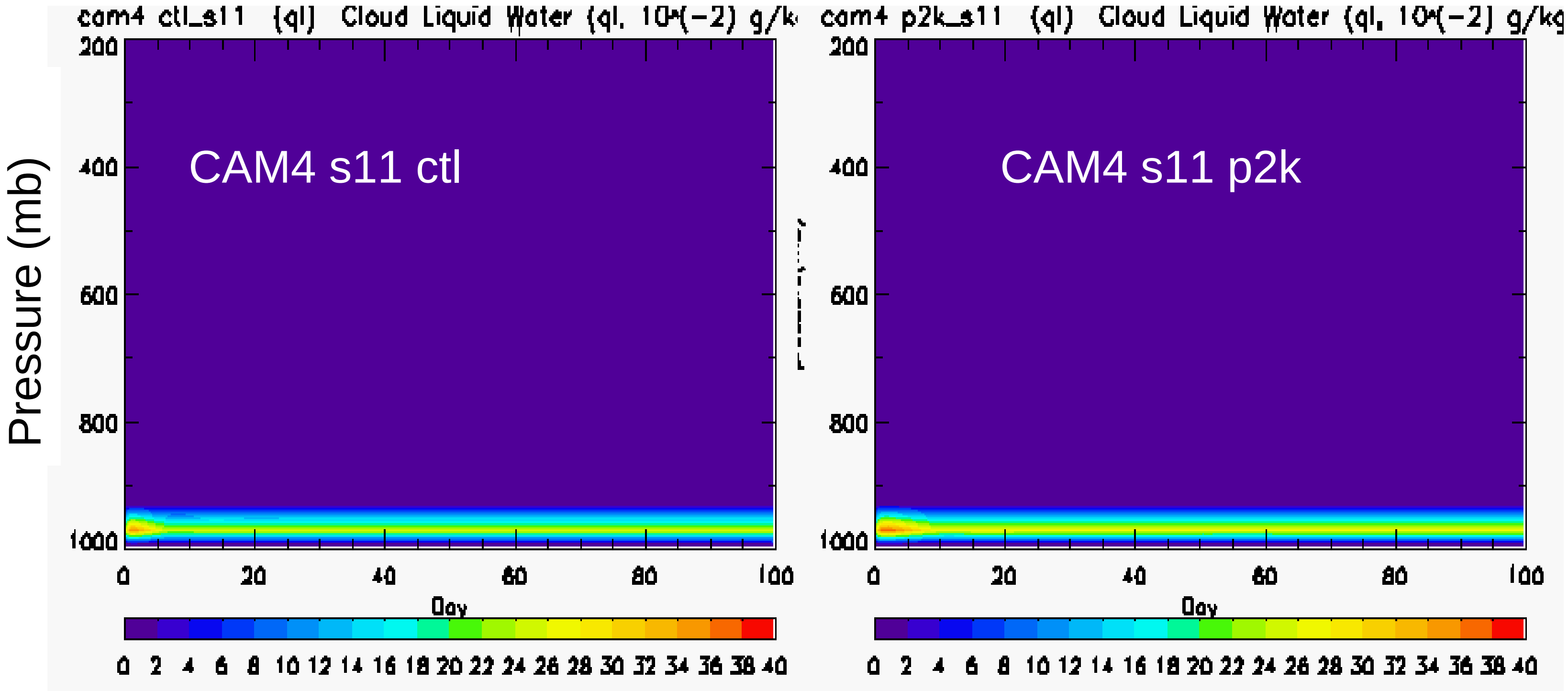


Cloud Feedback at S11: ΔCRF (W/m2)
s11: stratocumulus
20
10
0
-10
-20
ΔCRF
cam4
cam5
ccc
csiro
echam-eth
echam-mpi
ecmwf
ecmwf2
gfdl_32
gfdl_48
giss
gsfc
jma
jma2
lmd
racmo
ukmoL38
uwm

Example of negative feedback at s11

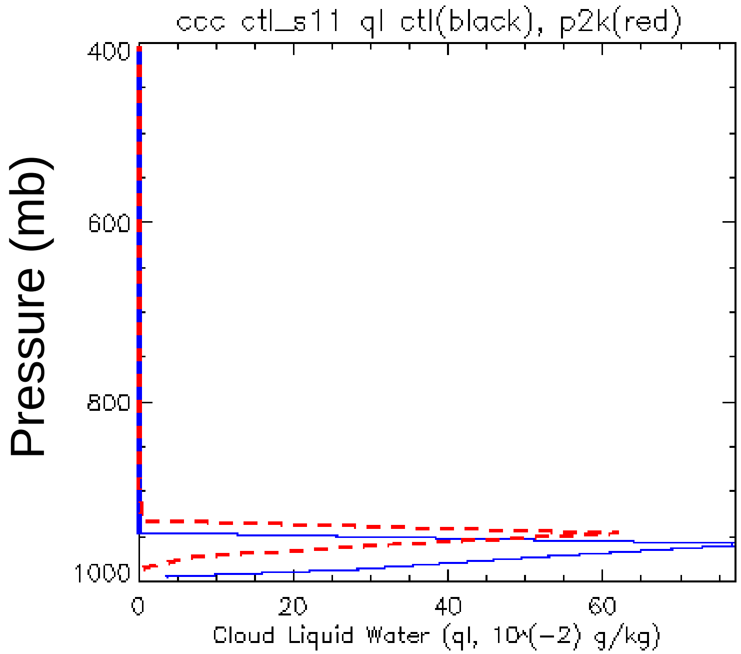
CAM4 cloud water ql

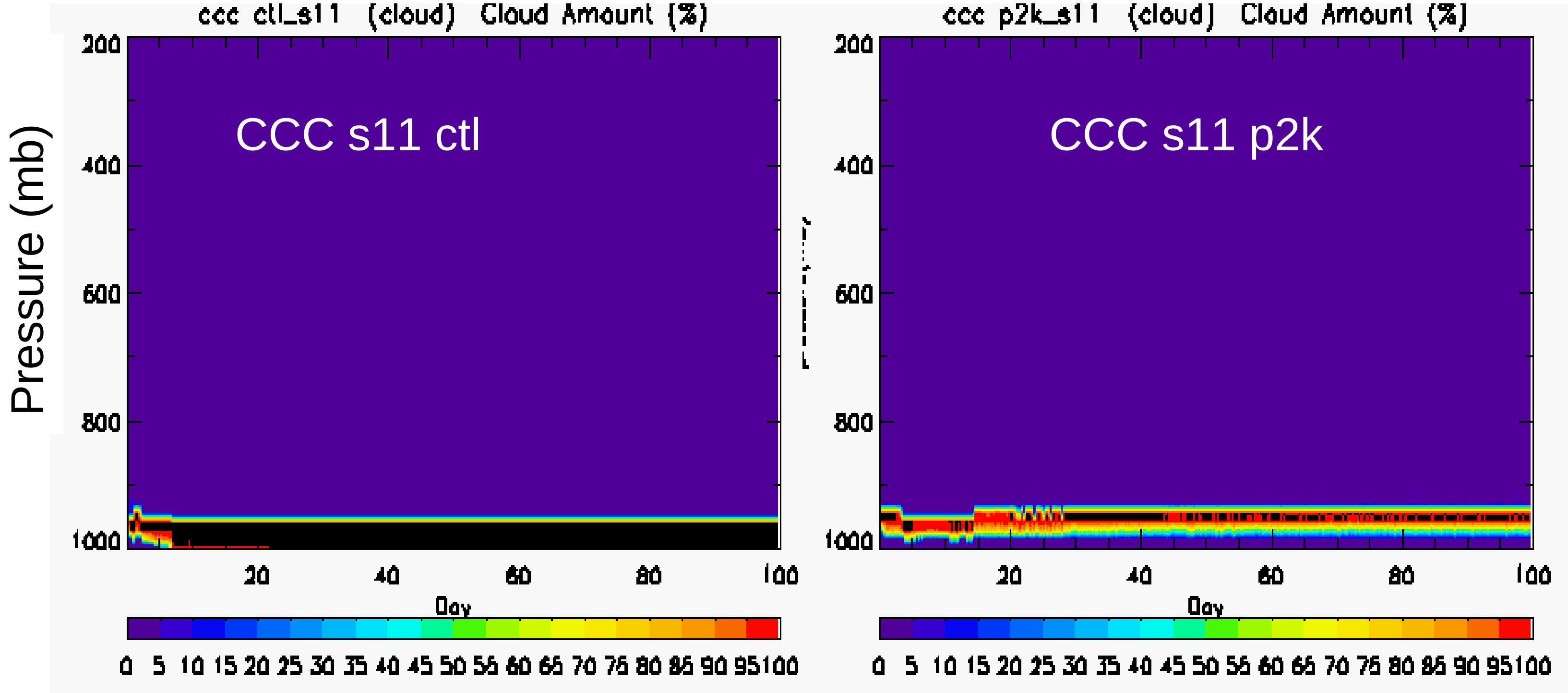


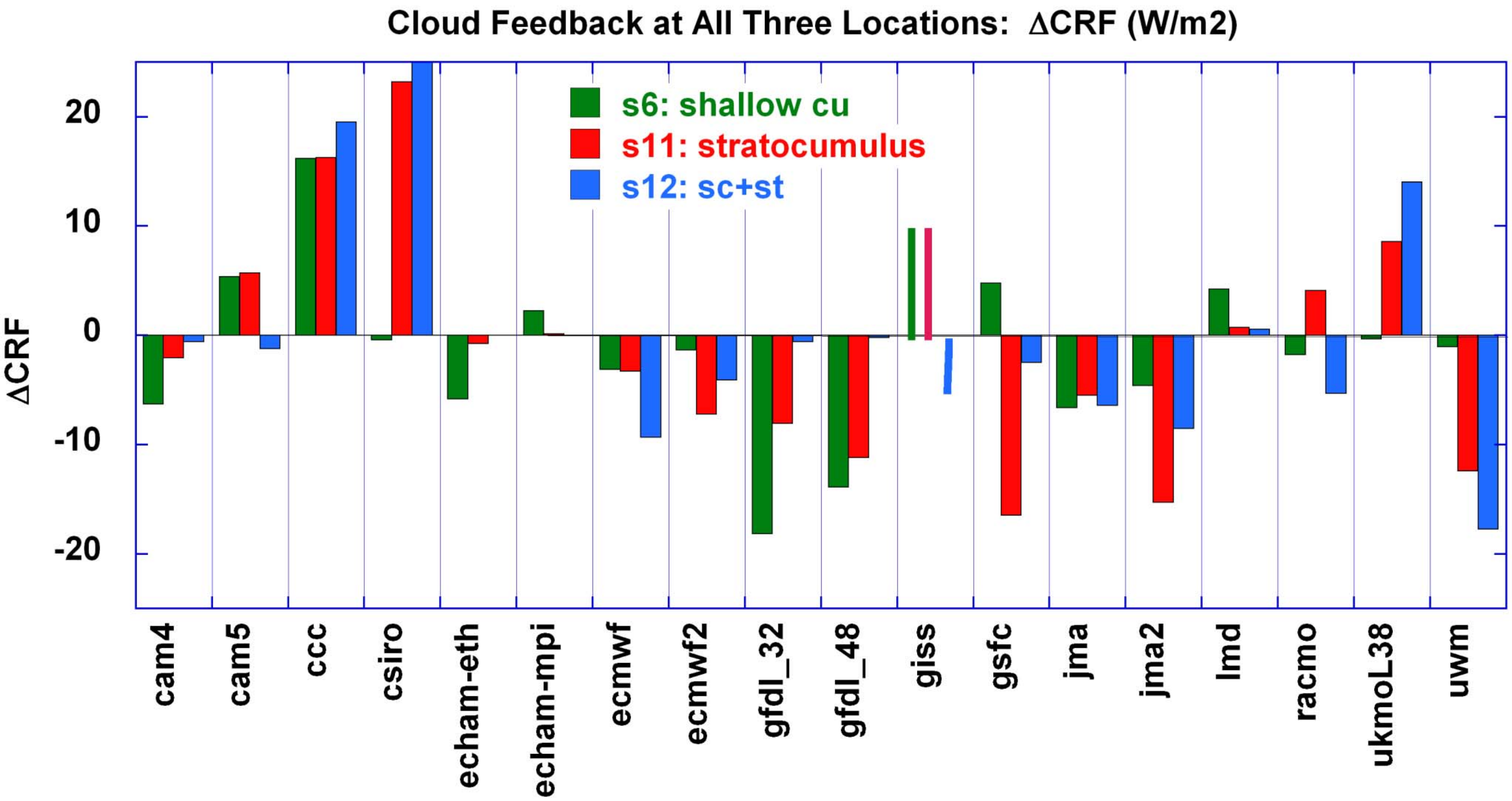


Example of positive feedback at s11

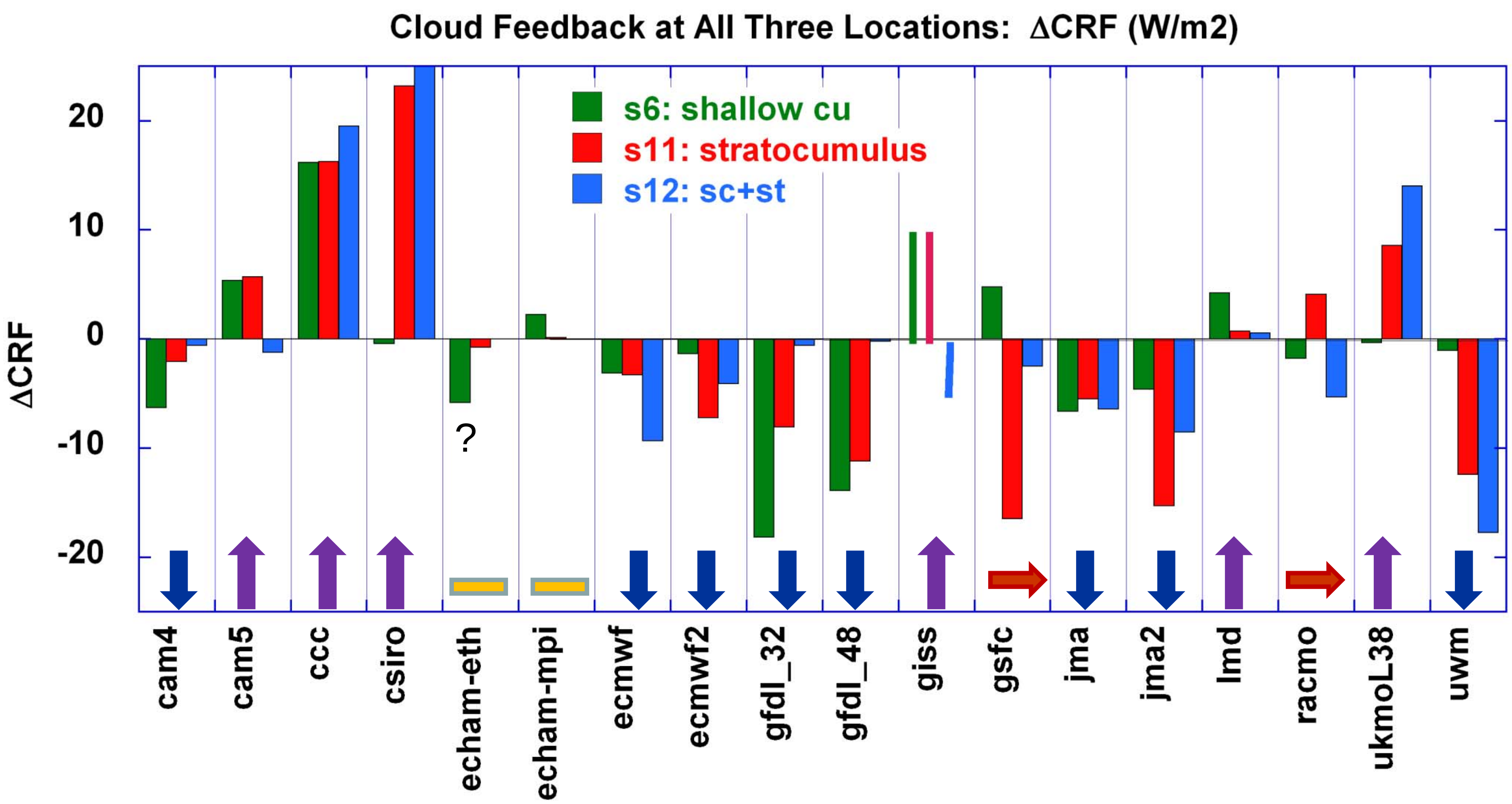
CCC cloud water ql







Cloud Feedback at All Three Locations: ΔCRF (W/m2)
s6: shallow cu
s11: stratocumulus
s12: sc+st
ΔCRF
20
10
0
-10
-20
cam4
cam5
ccc
csiro
echam-eth
echam-mpi
ecmwf
ecmwf2
gfdl_32
gfdl_48
giss
gsfc
jma
jma2
lmd
racmo
ukmoL38
uwm



6 models with positive feedback: CAM5, CCC, CSIRO, GISS, LMD, UKMO

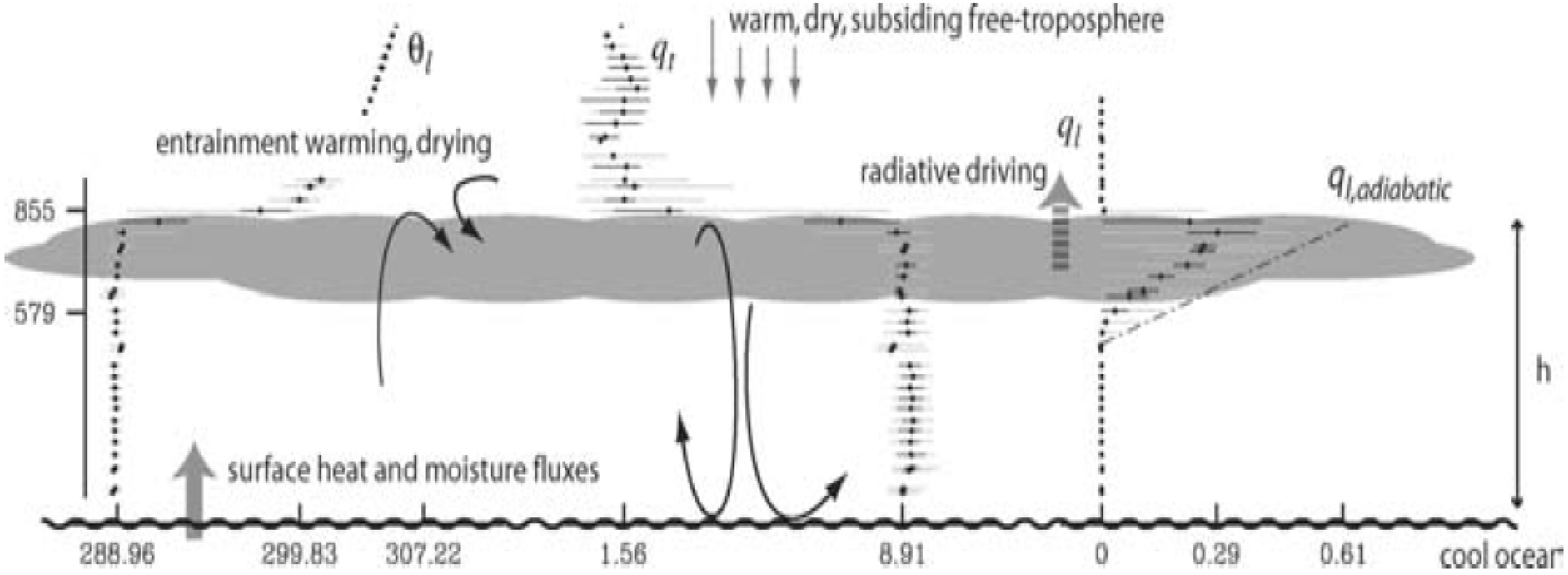
5 model with negative feedback: CAM4, ECMWF, GFDL, JMA, UWM

2 models with little feedback: ECHAM-ETH, ECHAM-MPI

2 models with different signs at the three locations: GSFC, RACMO

What are the physical mechanisms?

Turbulence, shallow convection, radiation, cloud microphysics



Stevens (2005)

PBL parameterizations:

1. K diffusivity

non-local K profile
counter-gradient

local	**Richardson number**
	TKE (MY-Level 2.5 or higher)

2. Explicit entrainment at top of PBL

3. High-order closure of turbulent fluxes

4. Hybrid (e.g., EDMF)

Well mixed boundary layer: (non-local, counter-gradient)

Cloud bottom: z_{cb} : $RH_s \times q^*(T_s) = q^*(T_s - \Gamma z_{cb})$

$$\frac{\partial z_{cb}}{\partial T_s} = \frac{1}{\Gamma}\left(1 - \frac{T^2_{v,z_{cb}}}{T^2_{v,s}}\right)$$

changes little

Cloud top:

Scaled by surface buoyancy flux or bulk Richardson number

$$R_{ib} = \frac{g}{\overline{\theta}} \frac{[\theta_v(z_{ct}) - \theta_{vs}] \times z_{ct}}{u^2(z_{ct}) + v^2(z_{ct})}$$

$$\theta_{vs} = \theta_s [1 + \varepsilon RH \times q^*(T_s)]$$

z_{ct} : **increases with Ts**

Cloud top liquid water increases with Ts: $q_l = RH \times q^*(T_s) - q^*(T_{z_{ct}})$

Negative cloud feedback

Explicit cloud top entrainment:

$$w_e = w_e(B_s, F_{rad}, E_{evap}) = -\overline{w}(z_{ct}) = \frac{-Q_{crad}}{(\partial\theta/\partial z)}$$

$$F_{rad} = F(q_l, C), \qquad E_{rad} = E(q_l, C)$$

$$\frac{\partial w_e}{\partial T_s} = \frac{\partial w_e}{\partial B_s}\frac{\partial B_s}{\partial T_s} + \left(\frac{\partial w_e}{\partial F}\frac{\partial F}{\partial q_l} + \frac{\partial w_e}{\partial E}\frac{\partial E}{\partial q_l}\right)\frac{\partial q_l}{\partial T_s} + \left(\frac{\partial w_e}{\partial F}\frac{\partial F}{\partial C} + \frac{\partial w_e}{\partial E}\frac{\partial E}{\partial C}\right)\frac{\partial C}{\partial T_s}$$

$$= -\frac{\partial\overline{w}}{\partial T_s} = \frac{\partial}{\partial T_s}\left[\frac{-Q_{cr}}{(\partial\theta/\partial z)}\right] \approx 0$$

$$\frac{\partial C}{\partial T_s} \le 0$$

positive cloud amount feedback

Besides cloud amount, all other factors lead to more entrainment in a warmer climate. If not countered, PBL will rise high enough to dry the PBL and break up the clouds.

Other cases:

PBL parameterizations:

1. K diffusivity

non-local
counter-gradient

local **Ri (positive possible via radiative cooling)**
TKE: Level 2.5 or higher (positive possible)

2. Explicit entrainment at top of PBL

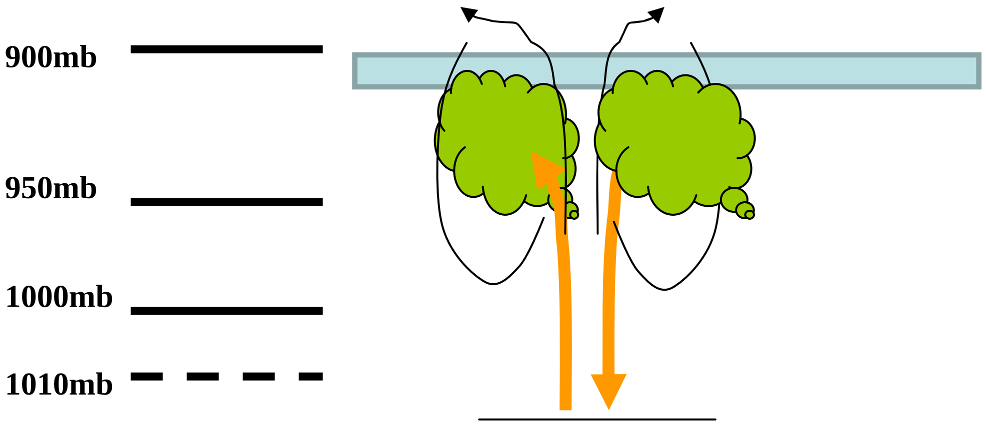
3. High-order closure of turbulent fluxes (well mixed or not)

4. Hybrid (e.g., EDMF)
(well mixed, depend on whether radiative cooling is enough to break clouds)

Other scenarios

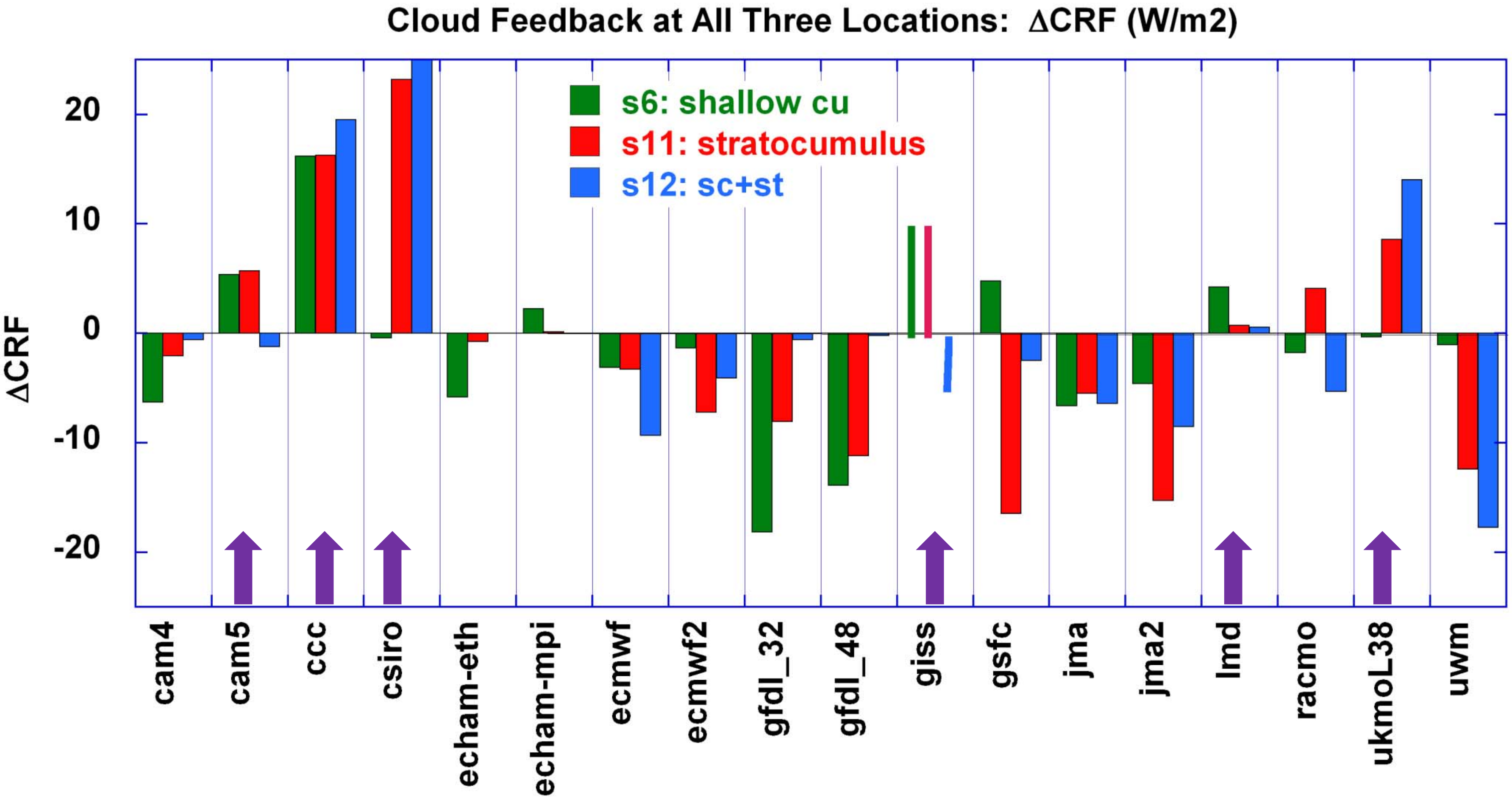
Shallow convection acts as the entrainment process, drawing dry and warm air down

But the warming and evaporative cooling occur over the entire convection layer, not just cloud top



Shallow convection is less efficient in breaking up clouds because it works over a deeper layer

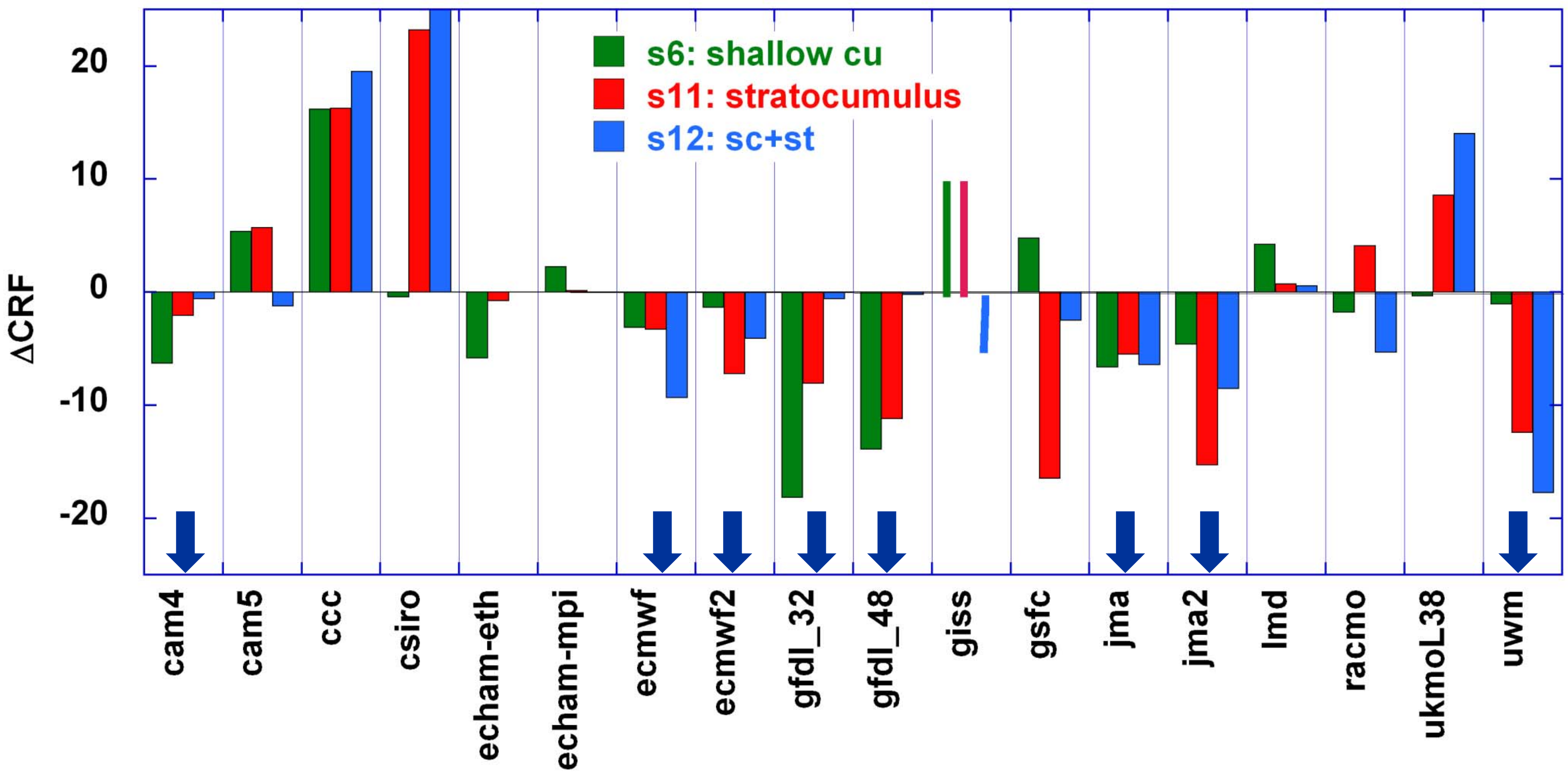
Interpretation of CGILS cloud feedbacks in different models



⬆ **<u>Six positive feedback models</u>: CAM5, CCC, CSIRO, GISS, LMD, UKMO**

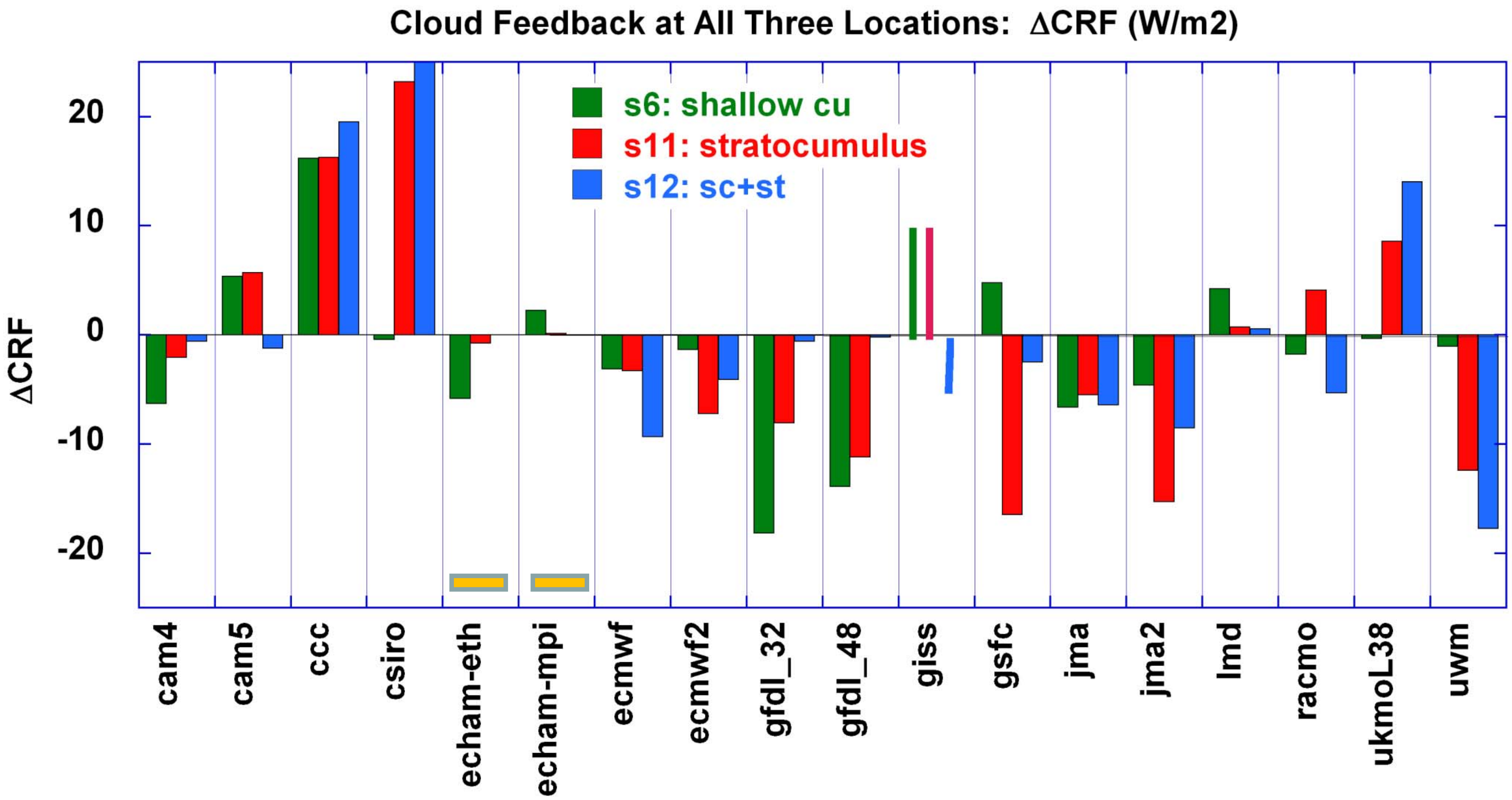
Explicit w_e: CAM5, CSIRO, UKMO
Level-2 MY (local): GISS
Richardson number-based (local) diffusivity: LMD
Non-local + Shallow Convection (?, Von Salzen and McFarlane): CCC

Cloud Feedback at All Three Locations: ΔCRF (W/m2)



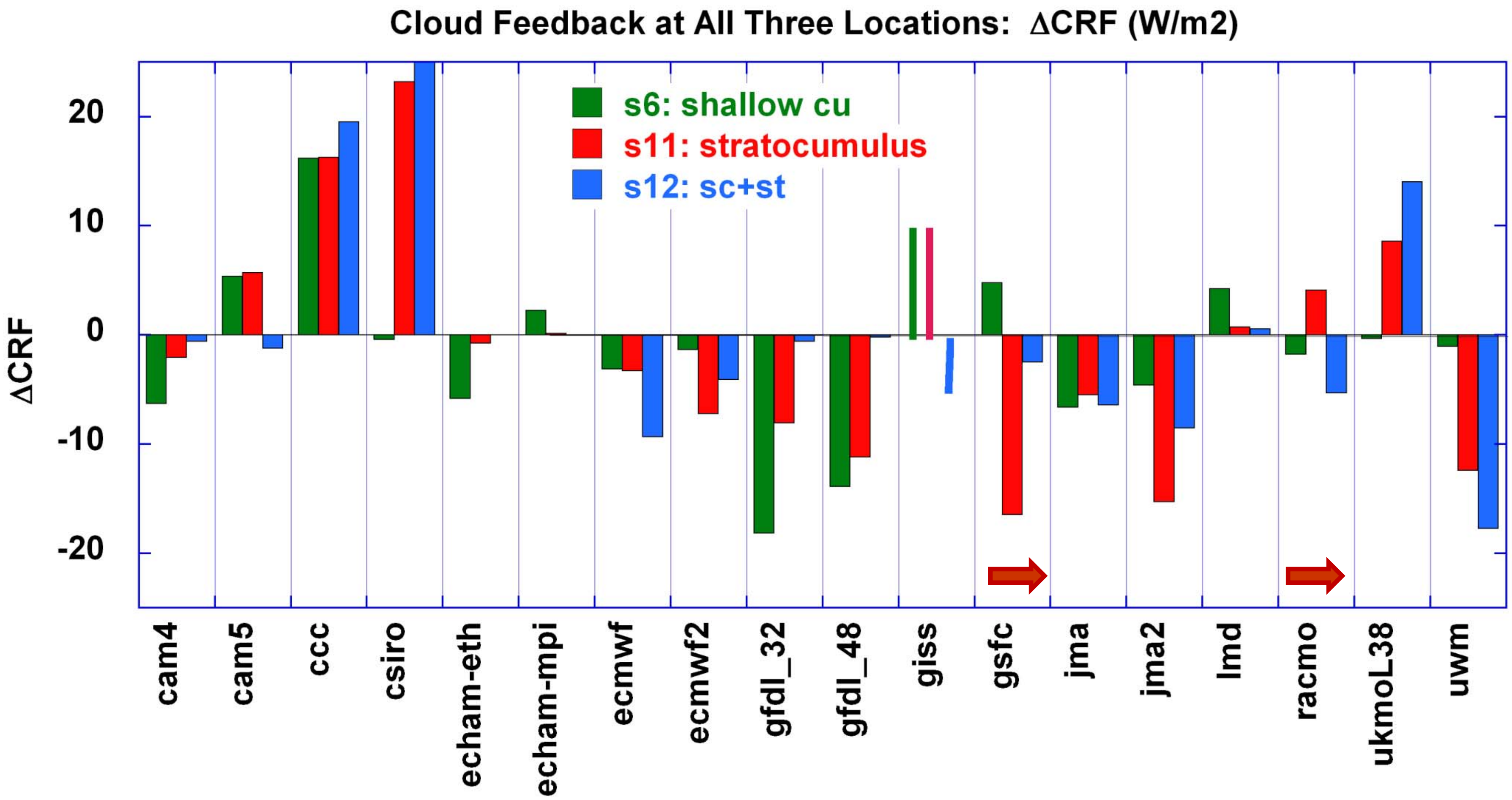
⬇ **Five negative feedback models**: CAM4, ECMWF, GFDL, JMA, UWM

Non-local, no w_e : CAM4, ECMWF
High-order closure: GFDL, UWM
Local Ri closure: JMA
Hybrid, EDMF, non-local, but explicit w_e due to radiation: ECMWF2



Two models with little feedback: ECHAM-ETH, ECHAM-MPI

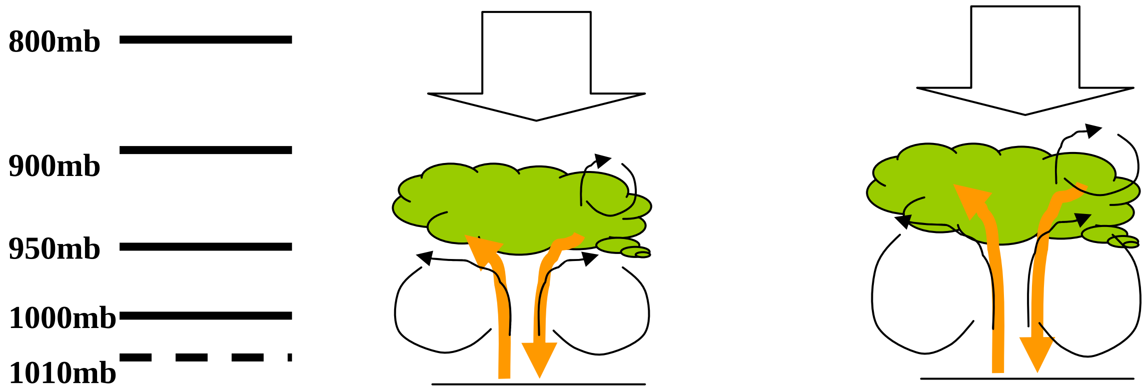
Brinkop and Roeckner 1995
Local K, dependent on 2.5 level TKE, and N^2



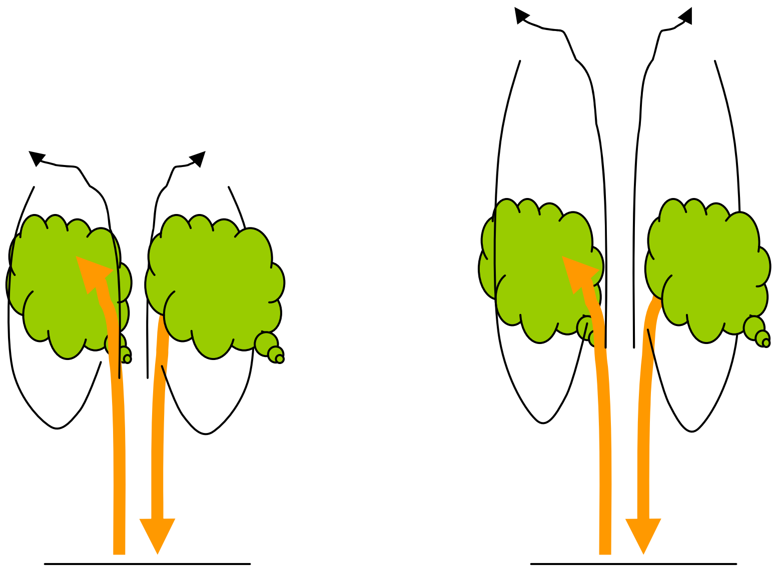
Two models have different signs at the three locations: GSFC, RACMO

RACOM: EDMF, non-local, but partially explicit entrainment
GSFC: 2.5 level of Mellor-Yamada (local)

Negative feedback



Positive feedback



Ambiguous, local or 1.5 order and higher

Summary

1. The experimental setup has produced robust signals of cloud feedbacks for the models as a group (consistency between constant forcing and transient forcing, consistency at different locations).

2. Models with well mixed PBL parameterizations (non-local Kh, counter-gradient, some TKE and higher order closure) tend to produce negative feedback. These can be explained using mixed-layer model.

3. Models with explicit cloud-top entrainment tend to produce positive feedback. Other schemes with similar attributes (local Kh, or dependent on N^2) may produce positive feedback.

4. These competing mechanisms may exist in some schemes, leading to positive or negative feedback in these models. In one case, shallow convection acts as a strong entrainment process.

CGILS Plan for Discussion

Immediate:

BAMS paper draft due to participants

This can be followed by a longer technical paper

Next steps:

- **Comparison with LES**
- **Comparison with CFMIP GCM results**
- **Use observed seasonal contrast to evaluate and constrain models**

Thank You!